



Innovative technology in the Pacific: Building resilience for vulnerable communities

Jeremy M. Hills^{a,b}, Evanthie Michalena^{b,*}, Konstantinos J. Chalvatzis^{c,d}

^a Institute of Marine Resources, The University of the South Pacific, Laucala Campus, Suva, Fiji

^b Sustainability Research Centre, University of the Sunshine Coast, Maroochydore DC, Qld 4558, Australia

^c Norwich Business School, University of East Anglia, NR4 7TJ, Norwich, UK

^d Tyndall Centre for Climate Change Research, University of East Anglia, NR4 7TJ, Norwich, UK



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ABSTRACT

Transitioning to sustainability will require innovation, not just in technological and economic terms but also in governance and culture. The work presented here sought a remote, vulnerable island context (Fiji, South Pacific) to enable further insight into the innovation process related to resilience and sustainability. The innovation targeted by this work was off-grid solar renewable energy (RE) systems framed as a development instrument to promote local, community-based resilience to climate change through increased livelihood security and reduction of climate change effects. Applying a local-level resilience framework to solar technology use, we conclude that the RE system can improve resilience, however, unintended consequences included a rush for energy usage causing a “tragedy of commons” of finite stored energy and subsequently increased supplementary fossil fuel use. This suggests that there are still missed resilience opportunities in the way that the innovation is implemented in developing countries and remote areas in particular. Further analysis demonstrated that improved planning at the socio-technological interface has the potential to strengthen communities' resilience. With significant RE investments required for a transition to a low-carbon future in many developing countries, there is a pressing need to effectively introduce innovative uses of technologies. Existential threats to many local communities, and some nations in the Pacific may mean that sub-optimal innovation will not be enough.

1. Introduction

1.1. Background

Sustainability is being increasingly seen as requiring a transformation or a transition, rather than being the inevitable consequence of contemporary development trajectories (Olsson et al., 2014). Successful achievement of ambitious Sustainable Development Goals (SDG) of the UN 2030 Agenda for Sustainable Development will require major transitions, not only in policies and technologies, but in modes of innovation. An expanding band of resilience scholars since the mid-1990s has been studying transitions toward improved ecosystem stewardship and sustainability (e.g. (Olsson et al., 2004; Chapin et al., 2010; Folke et al., 2010). Integrating transition management and resilience theory can contribute to the understanding of how to form niches for experimenting with initiatives that increase human well-being in the face of

uncertainty and change, while simultaneously supporting ecosystem capacity (Olsson et al., 2014). This key research focus areas invokes innovation and the dynamics of interactive innovation within which peoples, researchers, businesses and policy makers, and others can co-produce resilience and sustainability.

Innovation is framed not just in technological and economic terms but also in governance and culture. Island communities lend themselves to understanding such processes of innovation as they encapsulate many of the sustainable development challenges (Kelman et al., 2015; Connell, 2013) but are relatively small scale and unbuffered against shocks such as oil price spikes and natural extreme events. This small scale of island communities can make it easier to encompass diverse disciplines and information data within the same study (Mercer et al., 2010; Mercer et al., 2010). This multidisciplinary understanding is required for effective local responses to sustainability challenges, which is why island case studies have had such a large impact on participatory

Abbreviations: CO₂, Carbon Dioxide; GHG, Greenhouse Gas Emissions; INDCs, Intended Nationally Determined Contributions; IPCC, Intergovernmental Panel on Climate Change; LED, Light-Emitting Diode; MMM, Management-Maintenance-Monitoring; NGO, Non-Governmental Organisations; OGSS, Off-Grid Solar Systems; PSIDS, Pacific Small Island Developing States; PV, Photovoltaic; SDG, Sustainable Development Goals; UN, United Nations; UNFCCC, United Nations Framework Convention on Climate Change; USD, United States Dollars

* Corresponding author.

E-mail addresses: jeremy.hills@usp.ac.fj (J.M. Hills), michalena@hotmail.com (E. Michalena), k.chalvatzis@uea.ac.uk (K.J. Chalvatzis).

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processes for sustainable development (Kelman et al., 2011). There is resonance to the statement that “*Vulnerability is the birthplace of innovation, creativity and change*” (Brown, 2012) as measured by the interest of around 3.2 million people from around the planet (Walters, 2012). This work presented here sought a remote, vulnerable island context to enable further insight into the process of innovation implementation for resilience and sustainability.

1.2. Vulnerability, resilience and adaptation concepts in Pacific islands

Within the largest ocean of the world are located some of the smallest island countries. Pacific Small Island Developing States (PSIDS) are mostly remote and highly dispersed. Kiribati, for instance, has 112,000 inhabitants on 33 coral atolls which are spread over 3.5 million km² of ocean, an area larger than the land area of India. Most PSIDS have independent political systems with full jurisdictional autonomy and their own identity (Connor, 2008); they thus possess considerable self-determination of their development trajectory. However, this remoteness and self-governance is offset by economic reliance on other countries such as development assistance (World Bank, 2015; OECD, 2016). This high degree of international commitment in narrowly-based economics make those nations particularly attractive when it comes to promulgating innovation.

The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as the degree to which a system is susceptible to and unable to address climate variability and climate adverse impacts (IPCC, 2014). Vulnerability can also be conceptualised as “*a combination of the geographical and temporal proximity to a hazard (exposure) and the propensity for exposure to result in harm (sensitivity)*” (Jacobs et al., 2014). Between 2001 and 2010, natural disasters have, on average, affected 232 million people and caused more than US\$100 billion in damage worldwide each year (Guha-Sapir et al., 2011). In 2011, four PSIDS were in the top 15 World Risk positions (in terms of exposure, susceptibility, coping capacities and adaptive capacities) (United Nations, 2011a, 2011b). PSIDS are particularly sensitive to adverse impacts of climate change (United Nations, 2011a, 2011b; United Nations, 2011b; United Nations, 2015) leading to a capital stock loss 20 times greater each year compared to Europe and Central Asia (United Nations, 2015). Populations who live below the poverty line may be especially vulnerable to disasters (Maru et al., 2014); Fiji for example has >30% of the population living below the poverty line (Asian Development Bank, 2014).

Various forms of adaptation can be used to alleviate climate change vulnerabilities (Pelling, 2011). Adaptation refers to the decision-making process and the set of actions undertaken from individuals, communities, organisations and governments to deal with current or future predicted change (Engle, 2011; McLennan and Handmer, 2012; Fidelman et al., 2013; Keys et al., 2014). Increasingly authors argue that adaptive capacity is a function of household-level adaptive decision-making and action (Moser and Pike, 2015; Collins, 2015; Elrick-Barr et al., 2016). However, adaptation cannot suppress all climate-related impacts (Warner and Van der Geest, 2013; Warner et al., 2013; Mathew and Akter, 2015) particularly in small island states (Alliance of Small Island States, 2008; Monnereau and Abraham, 2013).

Most definitions of “resilience” include two key-elements: a) resilience concerns systems, countries, communities or households, b) resilience concerns the ability to manage exposure to hazards, shocks or stresses through maintaining or transforming living standards aiming at long-term prospects (Christopher and Rutherford, 2004; UNISDR, 2005; Cutter et al., 2008; UkAid, 2011; Akter and Mallick, 2013). Resilience is, therefore, a dynamic process and is characterised by multiple adaptive cycles interacting across a range of scales and dimensions (Brown and Westaway, 2011; Craeynest, 2010; Manyena, 2006). Fostering resilience, however, is difficult as is measuring resilience (CARI, 2017). This is probably the reason why there are projects aimed at improving the livelihood of vulnerable communities but which miss the

chance to reach optimal resilience gains.

1.3. Resilience and energy innovation in the Pacific islands

Innovation is generally considered to be the result of a process that brings together novel ideas/technologies in a way that they affect society and meet growing consumer demand (OECD, 2005; EPSC, 2017; OECD, 2010). The ability to innovate is also location specific (Tim, 2002). The miniscule land area of PSIDS within a vast ocean (1.8% land and 98.2% water (Fifita, 2012)) and limited domestic fossil fuel resources result in a heavy reliance on imported fossil fuels (Singh, 2012) and challenges related to energy security (Dornan, 2014; Michalena and Hills, 2016). Long diesel supply routes lead to oil cost escalation (Prasad et al., 2013) and the limited population spread across thousands of islands challenges fuel delivery. >95% of fossil fuel is imported into the Pacific (Woodruff, 2007a) and the energy demand keeps increasing (Bayar and Alp Ozel, 2014). It is estimated that 70% of Pacific households do not have access to electricity and the majority of those households are located in rural areas (Dornan, 2014). In Fiji, for example, more than one-third of Fiji's total import bill at the end of 2008 was accounted for by fossil fuels alone (Singh, 2012); this forces the Government to heavily subsidize electricity supply (Wolf et al., 2016). This state of energy poverty make PICs among the most vulnerable and indebted countries in the world and highly exposed to sudden or abrupt changes in external factors (Wolf et al., 2016).

Innovation in energy systems is a viable option to address energy resilience and security in countries with growing electricity demand, challenging economic circumstances and environmental targets (Michalena and Frantzeskaki, 2013; Chalvatzis and Rubel, 2015). All PSIDS are progressing with the roll-out of renewable energy (IRENA, 2016). Although PSIDS do not emit large quantities of CO₂ themselves (EU, JRC, 2011), the Pacific region is an assistance priority for development partners (Nutall et al., 2014; New Zealand Government, 2016). The focus on mitigation, through increased renewable energy feeding to grids, is apparent in the INDCs (Intended Nationally Determined Contributions) submitted by PSIDS to UNFCCC (Republic of Fiji, 2015). However, this focus misses some of the most vulnerable parts of PSIDS societies, the off-grid rural poor communities that produce negligible GHG emissions per capita but bear the brunt of climate change impacts. For those communities RE has no mitigation function as in their case they are trying to initiate electricity supply rather to switch to a lower carbon supply option.

Innovation in energy systems, both technological and integrative is fundamental in solidifying the benefits of renewable energy either in terms of controlling emissions (Zafirakis et al., 2015) or facilitating the energy supply chain in a wider interconnected system (Zafirakis et al., 2016). The innovative use of energy technologies can also create resilience for individuals, households and communities against the effects of climate change. The literature which tackles renewable energy's potential capacity to address adaptation and building resilience to climate variability at a local/community level, is limited (Stone, 2013; Perera et al., 2015). A systematic review (Perera et al., 2015) notes that “*only a few*” documents contained “*evidence demonstrating the link all the way through from access to energy to adaptation and building resilience to climate change and climate variability*”; this finding was significant in framing the energy innovation process as the object of study.

1.4. Scope and aims

Our research lens focuses on small, remote and traditional Fijian communities with customary tenure of natural resources. These communities are located in inherently vulnerable coastal locations with implemented household- and community-innovation in the renewable energy sector. Within this focus, we exclusively target innovation-created, place-based resilience accrued at the household- or village-level and accessible to the vulnerable and poor members of these

communities. There is a research need to better map the level of existing indigenous innovation capabilities across a range of different technological areas in poorer countries, in order to extend understanding of the role of innovation in alternative development pathways compared to those underpinned by existing energy socio-technical regimes (Geels, 2004; Geels and Kemp, 2007; Bryne et al., 2011). In addition, Olsson et al. (2014) noted the need for future resilience research in innovation and the social, technological and ecological interactions in relation to sustainability.

Although resilience can be a difficult concept to operationalise (Klein et al., 2003; Darnhofer, 2014) the work presented here uses case studies to provide an understanding of how innovation builds resilience within communities (Gawith et al., 2016). The innovation targeted by this work was off-grid solar systems which were new to the selected communities and new to the selected island and sparse nationally (Fiji) and regionally (Pacific). Those innovative solar systems are herein framed as a development instrument to promote local, community-based resilience to climate change through increased livelihood security and reduction of climate change effects. More specifically, the aim of the work presented here was to: (i) holistically assess how innovation is processed in the indigenous island communities, and (ii) to determine how this innovation process can be enhanced in terms of building resilience in vulnerable communities.

2. Methodology

In order to address the aims of this work a number of steps were taken. These included selection of study villages, development of a resilience framework, implementation of the resilience framework in the selected villages and then analysis of the results and further interpretation of potential further resilience opportunities.

2.1. Study villages and energy systems

This research presented here elaborates the process and the outcomes of recent off-grid solar systems that have been installed to supply electricity to two Fijian villages. Two villages were selected to be located on the coast so they potentially experience a combination of land and coastal climate change effects. The sites are remote, located a small island with no roads and no grid connection to the mainland. The authors engaged closely with the communities of the villages in order to identify some of the subtler socio-cultural resilience's dimensions and values.

The selected sites are two villages which are located in Beqa, a 36 km² island which is located 10 km south of the main island of Fiji (Vitu Levu). These two villages, Naceva and Rukua, belong to the Central Division, Rewa Province, Sawau District and while the distance between them is <5 km, they can be accessed only by boat. Like most rural Fijian villages, the communities are made up of traditional Pacific Islanders who undertake traditional farming and fishing activities.

Two off-grid solar systems were studied in the selected villages: stand-alone household-level solar units (in Naceva village) and a centralised solar unit with a local grid supplying all village households (in Rukua village). Two different off-grid systems (household- and village-level) were selected in order to compare possible differential dynamics in the innovation process. Innovation in battery energy storage systems and their connectivity to PV panels has made possible the use of energy storage in these villages in order to maintain supply in the evening hours and when there is no adequate sunshine. The Naceva household-level systems were implemented through the Rural Electrification Policy on 15 of the 42 houses of the village. Each participating household had to pay installation fees of FJ \$100 (~USD \$48) and then FJ \$10–20 (~USD \$5–10) each month for the system maintenance. The low number of installations was due to the low number of households that could afford the installation fee. One person was selected from the village to inform the government to come and conduct repairs and

collect dues. So far, for the last four months that household solar systems were installed, the community was satisfied from the operation and efficiency of the systems.

In Rukua, the centralised solar project was termed the “Rukua Smart Solar Power project”. This installation was a USD \$ 800,000 joint initiative between Fiji government and the Inter-Action Corporation of Japan and represented the first solar energy system being built at village level in Fiji. In his speech the Prime Minister stated that the main drivers behind this initiative were, a) energy independence of Beqa, b) commitment to increase reliance on renewable energy, and c) “*the unlocking of a number of development opportunities thanks to the provision of a reliable source of energy*” (Bainimarama, 2013). The Rukua system was a 20.5 kW (108 piece, 190 W monocrystal) PV solar system with 120kWh valve-regulated lead-acid battery-based (VRLA) storage for 77 households with an installed meter (Interaction Corporation, 2015).

2.2. Development of a resilience framework

To assess the contribution of off-grid renewable energy schemes to place-based resilience a renewable energy framework on resilience was created. The main resilience components and dimensions of this framework were identified through a literature review coupled to expert judgement. As electricity access is among the first priority among rural communities and a service for which rural communities are willing to pay (Niez, 2010), we focused on the existence/creation of place-based resilience in relation to energy systems for those communities. To that end a comprehensive review of scientific literature (through Scopus) as well of grey literature was carried out. Rather than a single or composite suite of search terms, a wide range of terms were used to elaborate specific aspects related to resilience accrued from energy systems. This search was carried out until new literature was not providing new information on which to base or modify the existing list of resilience dimensions, suggesting that the resilience dimensions were at least exhaustive.

To structure these various resilience aspects identified from the literature, information was collated into three resilience components which were defined within the context of this study as follows:

Physical energy resilience (PH) – aspects related to the tangible energy system infrastructure function and operation.¹

Socio-ecological resilience (SE) – aspects related to the ability of the individual, communities and socio-cultural assets to be maintained or consensually modified in light of climate change impacts/ internally organised structure and architecture to manage/govern affairs.²

Institutional-organisational resilience (IO) - externally imposed structure and architecture which positively affect or influence community affairs.

Within those three components, 29 resilience dimensions were identified which were relevant to the studied villages (6 for the physical component, 14 for the socio-ecological component and 9 for the institutional-organisational component). The dimensions were based on interpretations of the literature, or in some cases based on expert judgement of the authors (Table 1).

Each dimension was scored using a four point Likert scale reflecting

¹ Linkages between the energy system itself and the disturbances because of the climate change as well as responses need to be understood (Perera et al., 2015) note the little empirical evidence on this issue, while they point out that the lack of this understanding might result in maladaptation.

² The significance of the link between access to energy and social capital/activities (for instance, “how new incomes generated through provision of energy access are being used, and are the new livelihoods created through provision of energy access impacting existing livelihoods and markets”) has been stressed by (Perera et al., 2015) in their review of all literature concerning energy and adaptation.

Table 1

The resilience categories/components, dimensions and key references.

Dimension	Acronym	Description	Key literature
a) Physical resilience			
Electricity Systems Reliability	P1	Need for electricity independency and autonomy	
Prevention	P2	Need for measures which will prevent the electricity systems from breaking down	
Repair and recovery mechanisms	P3	Need for electricity systems which are of low maintenance needs	
Electricity supply flexibility	P4	Choice between alternative electricity sources	
Robustness within financial ROI	P5	Cost-effectiveness of electricity systems used	
Balance between the use of natural resources and infrastructures	P6	Ability to balance electricity requirements/supply with local natural resources	DOE-PI; NREL (2013)
b) Socio-ecological resilience			
Autonomy on decision-making	SE1	Autonomy of the community to make and implement decisions	Fidelman et al. (2016), Gawith et al. (2016)
Leadership	SE2	Ability of actors to direct and motivate others to follow	Fidelman et al. (2016), Gawith et al. (2016)
Risk assessment and management/preparedness	SE3	Ability of communities to assess risks and manage them in a way to get prepared to meet environmental hazards	(Berke et al., 2008)
Problem-solving capability	SE4	Capability of communities to navigate challenges and/or draw on traditional knowledge	Wade (2003), Folke, Resilience: The Emergence of a Perspective for Social-Ecological Systems Analyses (2006)
Learning capacity	SE5	Creation of Information Security (through education/knowledge generation/research). Dissemination and feedback loops (creation of awareness around RE).	Gupta et al. (2010)
Social learning	SE6	Use of renewable energy for social learning (installed on schools, hospitals, etc)	Cutter et al. (2008)
Acceptance for innovation	SE7	Ability to accept innovative systems (e.g. watering systems which can work with solar electricity).	Gawith et al. (2016), Frumhoff et al. (2015)
Ability for transformation/Paradigm Shift	SE8	Ability to learn, change systems, and adapt referred to as 'dynamism'	Darnhofer (2014), Gawith et al. (2016)
Collaboration between actors (at a community level)	SE9	Ability of community agents to work together to improve community resilience	Ebbin (2009)
Health and well-being	SE10	Suitability of the electricity technology to meet health and well-being living needs of people	Berke et al. (2008)
Livelihood security/business resilience	SE11	Economic activities and development, financial stability and security, money saving/affordability	Electric Power Research Institute (2009)
Routinization of conflict	SE12	Coping with conflicts	Mala et al. (2009)
Improvisation	SE13	Ability to operate a system when no spare parts are available	Dornan (2011), Mala et al. (2009)
Ownership management/responsibility	SE14	Level of community's engagement with the solar systems	Ebbin (2009)
c) Institutional-organisational resilience			
Institutional & regulatory nesting and linkages/institutional support	IO1	Need for institutional and regulatory back-up during demanding circumstances	Cutter et al. (2008)
Fit-for purpose mainstreamed policies, codes and standards	IO2	Compatibility of systems with policy, of systems on-site, etc	Dornan (2011)
Complementarity/variety of electricity strategies (policies)	IO3	For example how renewable energy can work together with energy efficiency measures at the community level	Ebbin (2009), Gawith et al. (2016)
Interconnections between policies (operational planning)	IO4	Need for the design of a national system integrating multiple infrastructures (energy, health, water, etc)	Fidelman et al. (2016)
Flexibility on decision-making regarding electricity affairs	IO5	Need for decision-making flexibility necessary (eg. Oil prices fluctuations or/and to avoid bureaucratic problems).	Ibanez et al. (2015)
Monitoring (and data collection?) & Reporting	IO6	Government request to the Community to address quality control problems through consistent monitoring, measurement, data collection and reporting	Dornan (2011)
Prevention (from the governmental side)	IO7	The intervention from the Government so as communities are more prepared to respond to environmental hazards	DOE-PI; NREL (2013), Dornan (2011)
Engagement in national debate	IO8	Degree to which the community feels engaged to the national debates on energy/climate change	Electric Power Research Institute (2009)
Cohesion between community and government	IO9	The tendency of the community to align with government's pursuits	Miara et al. (2013)
			Alchian and Demsetz (1972)

the extent to which the energy system intervention had led to an increase in resilience compared to the situation prior to the intervention. The scoring system was zero (“-”) when there was no discernible effect of the energy system intervention on that particular resilience dimension, “x” with a negligible increase, “xx” with a medium-level increase and “xxx” with a significant improvement reflecting the maximum attainable in that resilience dimension. The intent of the scoring system was to help identify the indicative portfolio of effects that the energy system intervention had on the village level resilience of the targeted communities.

2.3. Application of the resilience framework

The two village chiefs were contacted by a local agent (born and living in Naceva village) to facilitate arrangements for a discussion with the community. For Naceva this involved a visit to the village and a whole-of-village meeting with the traditional “sevusevu” respect offering of cava roots. This meeting was carried out using a Fijian translator for a majority of the discussions. For Rukua, meeting in the village was not an option as the community was too busy, thus a delegation was sent from the village to Lawaki Resort for a formal meeting. The delegation consisted of the village chief, two village elders and the designated community solar officer who was the individual selected to collect solar electricity dues with the provincial government

office and report any maintenance or repairs. As all the Rukua delegations were competent English speakers, this interview was carried out without a translator.

The resilience framework was unpacked into a number of questions pertaining to each dimension and this was then used to guide the discussion in both villages to ensure coverage was achieved of all dimensions. Traditional proceedings and interviews lasted 2–3 h. Following the interviews and during the analysis stage, further questions were asked to validate the correctness and completeness of information this was through telephone or e-mail communications with identified local people.

3. Results

3.1. Assessing village-level resilience

The level of resilience on the established Likert scale for each dimension was assessed by the authors based on the interviews in the two villages. The answers from the interviews provided insights on how the projects scored on the resilience dimension and also offered a broader understanding on how the projects have failed. The assessment of answers was primarily carried out by consensus between the two authors involved in the interviews and using the third author as a further independent source for verification. Table 2 presents the scoring and justification. This data demonstrates both similarities and differences in the place-based resilience portfolio for these neighbouring villages in relation to the use of renewable energy systems.

When it comes to physical resilience (PH, Table 2a), most noticeable is the high score for the financial robustness of the system (dimension PH5); the high score is related to the negligible contribution for the household system in Naceva (USD \$48 overall installation charge per household) and the system provided for free in Rukua. For socio-ecological resilience (SE, Table 2b), there is an existing traditional community-based system (in which regular village assemblies provide guidance to the chief); this system contributes to the high level of SE1 (decision-making). These village-level established processes also seem to contribute to many other of the SE dimensions. However, the energy system intervention did not have any impacts on SE6 (social learning), SE12 (conflict resolution), SE13 (improvisation) and it also had limited influence on livelihood/business resilience. The institutional-organisational (IO) scorings (Table 2c) were quite different between the two villages. In Naceva the household level renewable energy system seemed to contribute to resilience (e.g. IO1 – IO3), whereas in Rukua the system was neither considered as fit-for-purpose or complementary to other energy systems (IO2–4). The higher levels of dimensions IO5–9 in Rukua reflected strong external engagement, especially with the government; the Rukua village chief and elders were well informed and were involved in the provincial and national debate on sustainability.

The initial conclusion from this analysis is that the solar system has provided additional resilience to the village in the PH, SE and IO dimensions, although there were some differences between the villages partly related to the type of implementation of the solar system (household stand-alone applications in the one village, central solar system in the other village). However, from the interviews further dynamics were identified especially in the village-wide energy system in Rukua. The system in Rukua was implemented through Japanese development assistance with what appears to be minimal discussion with the village beyond the request by the chief to the Prime Minister. There was no evidence that the solar system that has been implemented was designed to meet the needs of the village, beyond calculation of the number of households to connect. Positioning such modern innovative technology in a traditional village had a number of largely undesirable connotations beyond those identified by the resilience dimensions:

“Tragedy of the commons” - Rukua village was told by the solar system installers that they could run no > 3 fridges so as not to drain

the system. There appeared to be no internal discussion or external designation of who or where these fridges would be placed; therefore, the villagers purchased 30 fridges which - when connected - drained the electricity supply once it was running on battery after sunset. Due to the lack of any organisation about use of the energy, the village exhibited a “tragedy of the commons” (Ostrom, 2015) in which each household tried to maximise its benefit from a finite resource.

Unsustainably low tariff setting - each household was metered for its electricity use and charged at a set rate and payments were made monthly. The rate was estimated based on collection of adequate money to replace the batteries after 5-years of use. This per unit rate was low as it did not include any re-payment of the installed renewable energy equipment and supply system or for the system maintenance. This was a facilitating factor in the “tragedy of the commons” as the unit price did not limit usage and failed to promote any attention to energy efficiency and conservation. In addition, in financial terms, the energy system has not proved sustainable, as electricity usage charges only covered battery replacement and not equipment maintenance and repair.

Increased fossil fuel use - after the implementation of the solar system, and following the lack of repair of the system in 2016, subsequent daily electricity draining of the batteries led to 6 households starting to run fuel generators once the supply was run down, each of which consumed 20 l per week making a village total of approximately 120 l per week. Previously, when the village was connected to a central generator for daily electricity supply from 18 h00 to 21 h00, the usage was 40 l per week. This means that, according to these figures from the village, Rukua is now using about three times the amount of fossil fuel for electricity that was used prior to installation of the renewable energy system.

Implementation of the energy system in Rukua thus seems to have inspired an energy “rush” which led to a “tragedy of the commons”, lack of regard for energy efficiency due to low pricing of electricity and overall an increased fossil fuel use. In Naceva, the system was household-based and thus not a common resource at the village level; meaning that a “tragedy of the commons” situation could not occur. Fixed, regular payments were submitted as rent for the installed system rather than for units of electricity used. Households self-limited their usage to whatever was generated/stored through use of appropriate appliances (e.g. LED lights, mobile phone chargers) obviating the need for additional fossil fuel generators.

3.2. Designing innovative interventions for resilience

It is clear that both the Naceva and Rukua systems have brought resilience benefits such as strengthening the community-level decision making process, enhancing links to the governmental system and improved communications in disaster situations (Table 2). However, it also appeared that the energy systems were minimally embedded in the respective communities. Discussions on how to use the renewable energy for economic benefit, supporting new livelihood activities or for communal services (such as communal fridges for storage of fish catch) did not happen. The energy provided for more comfortable living (e.g. lights and mobile phones) rather than as an instigator for enhancing livelihood sustainability, growing economic benefits or more resilient development (Zafirakis et al., 2014). It was concluded from this analysis that there were missed opportunities in the way that the installations were carried out in terms of building village-level resilience.

Consequently, based on the resilience portfolio for Naceva and Rukua, we designed a model of intervention which could potentially build further resilience in these communities on the back of the renewable energy installation. The model was based on expert consensus of the authors and used as an indicative demonstration of what further resilience could be captured in lieu of possibilities for practical

Table 2

The resilience dimensions of Naceva and Rukua village. Scoring: From “-“ (=no resilience) to “XXX” (=high resilience).

Resilience dimension	Naceva village	Rukua village	comments
a) Physical resilience			
PH1: Electricity Systems Reliability	XXX	X	The solar system at Naceva is too new to allow reliability assessment but no issues were reported and construction appeared sound. The system at Rukua is partially not working for over 5 months maybe due to TC Winston cyclone impacts.
PH2: Prevention of electricity systems breaking down	–	X	Repair reports are addressed to the Government. There is no prevention policy foreseen from the Government. Both villages host “reporting persons” (individuals whose main responsibility is the monitoring of solar system and the problem reporting; however, there is no training on prevention processes or/and repairs).
PH3: Repair and recovery mechanisms	X	X	Naceva submits fees and damages report each six months to government. Rukua has a repair agreement with the government for the first 5 years of operation but the government responds slowly.
PH4: Electricity supply flexibility	XX	XX	Both villages have as fall-back stand-alone household generators as well as independent solar lights, and kerosene lamps.
PH5: Robustness within financial ROI	XXX	XXX	Systems are mainly paid for by external funds, contributions by villagers were minimal so the household/village ROI is very high.
PH6: Balance between the use of natural resources and infrastructures	X	X	The link identified between infrastructures is limited. Rukua did identify that there is inadequate water volume and consistency for small hydroelectric scheme; Naceva confirmed that there is adequate water volume for a small hydroelectric scheme.
b) Socio-ecological resilience			
SE1: Autonomy on decision-making	XXX	XXX	Both villages have traditional communal decision making process informing the Chief through regular meetings.
SE2: Leadership	X	XX	Both villages displayed strong leadership in obtaining energy systems but negligible leadership displayed in allocation use of electricity at household level.
SE3: Risk assessment and management	X	XX	Naceva has no plans for disaster situations just report renewable energy problems every 6 months. Rukua has good disaster planning but limited energy risk management beyond battery replacement fund.
SE4: Problem-solving capability	X	XX	Both communities are aware of the process on how to problem-solve but rely only on third parties; Rukua has identified one person who should be responsible to report problems.
SE5: Learning capacity	X	XX	Both communities have now better information (TV, internet) for learning on disaster warning and energy efficiency. Naceva have minimal interest in learning about energy systems but Rukua is interested in energy system functioning and basic maintenance.
SE6: Social learning	–	–	There is no social learning in place. Energy is perceived as a household and not a community issue. Solar systems are not connected to public buildings; except one church in Rukua, which allows parishioners to listen to rugby on their headphones while attending the mass.
SE7: Acceptance for innovation	XX	XX	Communities are willing to accept innovation if this comes for free; however there is limited willingness to invest even minimal contributions if there is the slightest risk incorporated to this new technology.
SE8: Ability for transformation/paradigm Shift	–	–	There is minimal evidence of paradigm shift or any intention; the focus is on making life more comfortable with TVs and phone chargers. There is no thought of economic opportunities.
SE9: Cooperation/collaboration between actors	XX	XX	Chief acts as village representative to government (iTaukieiaffairs) and is informed by regular village meetings. There is involvement of NGOs in non-energy activities e.g. marine protection.
SE10: Health and well-being	X	XX	Improved well-being as feel better informed of disaster risks and more in touch (TV, Facebook etc.). Both Naceva and Rukua note the less kerosene fire risk and the fact that children can study during evenings. But neither direct health nor improved resilience, through dedicated community energy use for food and medicine storage etc., was noted.
SE11: Livelihood security/business resilience	X	X	There is no consideration of energy as a promoter of economic activity; however the benefit for reduced costs for petrol for generators and kerosene for lights has been emphasised by both Naceva and Rukua.
SE12: Routinization of conflict	–	–	There is minimal intra-village conflict and traditional mechanisms are employed. In Rukua, the overuse of energy by households was blamed on the government for not repairing the system, rather than individual households.
SE13: Improvisation	–	–	Both villages wait for help and no improvisation ability was noted in relation to energy.
SE14: Ownership management/responsibility	–	X	In Naceva all ownership and responsibility is devolved to the government. In, Rukua, the situation is similar except for the metering system which aims to permit community-funded battery replacement after 5 years.
c) Institutional-organisational resilience			
IO1: Institutional & regulatory nesting and linkages	X	XX	Both villages are aware that renewable energy was implemented through the Rural Electrification Policy. Rukua involved both the Fiji Prime Minister and subsequently the Japanese Ambassador in Fiji to obtain the system.
IO2: Fit-for purpose mainstreamed policies, codes and standards	XX	–	In Naceva the household systems seem to be fit-for-purpose. In Rukua, the system is partially broken down and unrepaired for months so maintenance standards are inadequate.
IO3: Complementarity/variety/diversification of electricity strategies	X	–	In Naceva, there is basic awareness of energy efficiency on household system. In Rukua, there is no control or awareness on energy use and nature of energy supply.
IO4: Interconnections between policies	–	–	There is no evidence of interconnections.
IO5: Flexibility on decision-making regarding electricity affairs	–	XX	Government decides, pays and owns energy systems in both villages with minimal engagement from the villages. However, government responded and delivered to the energy needs of Rukua as stated by Chief, even if went through a foreign party.

(continued on next page)

Table 2 (continued)

Resilience dimension	Naceva village	Rukua village	comments
IO6: Monitoring (and data collection?) & reporting	X	X	The technical monitoring is limited to registration of problems and call for repairs. In Rukua, there is village-level monitoring of usage solely for purposes of charging households for battery replacement.
IO7: Prevention (from the governmental side)	–	X	The Chief of Rukua has been trained in disaster prevention for his village and has a preparation plan.
IO8: Engagement in national debate	–	XX	Rukua representatives are knowledgeable on climate change, coastal protection and marine resources. However, there is no link made between the village energy system and climate change. This is reported through the Provincial meetings that the Chief attends.
IO9: Cohesion between community representatives and governmental officers	X	XX	In Naceva, there are minimal links with government. In Rukua, the Chief is a representative on the Provincial Committee for Rewa province and Ministry of i-Taukei Affairs although this does not seem to affect maintenance schedule by other government departments.

Table 3

Proposed additional interventions to promote further resilience through the RE systems of Rukua and Naceva and the (positive) effects on resilience framework.

Intervention	Description	Primary effects
Management		
1. Assessment (and update) of energy infrastructure	Looking for possibilities for use of battery storage or/and micro-grids, micro wind-generators etc. (as more energy choices means more resilience). Innovative energy storage technologies have been investigated by authors as means of coping with wind or solar energy intermittency (Zafirakis and Chalvatzis, 2014).	PH1, PH2, PH4, PH6, SE7, SE8, SE13, SE14, IO3, IO4, IO5
2. Increase of information incoming & relevant discussion in the villages	For example, Information on the creation of links of electricity access to other economic developments (tourism, fishing, trade, electricity business, etc).	PH6, SE4, SE6, SE8, SE11, SE12, SE14
3. Community Energy management	Creation of an agreed community approach to management of solar resource and exploitation rights and compliance measures within the traditional village leadership governance structure.	PH1, PH2, PH6, SE1, SE3, SE4, SE6, SE9, SE12, SE14, IO5, IO6, IO9
4. Development of participatory future scenarios	Development of participatory scenarios for future optimisation of community and individual wellbeing benefits and possible innovation-based paradigm shifts with wide community engagement and the facilitate decision making to a consensual future trajectory Action Plan.	SE6, SE7, SE4, SE8, SE11
5. Reporting	Development of a village system for recording energy usage and assessment of benefits in relation to government policy objectives	PH3, PH5, SE1, SE4, SE5, SE9, SE12, SE14, IO2, IO3, IO4, IO6
6. Enhancement of collaboration with government	Closer interaction with the government, for example, through communication of data collected through monitoring of OGSS (see monitoring process recommended above). Participation of communities at local energy planning performed by the Government and in Committees concerning the outcomes of OGSS implementation or (for example) to securing long-term maintenance funding.	PH3, SE4, IO1, IO2, IO6, IO7, IO8, IO9
7. Introduction to energy saving measures	Measures for increase of electricity supply to be accompanied by reduction of electricity demand (through energy saving measures). Government should make sure that all households comply with best-practice energy efficiency standards and practices.	PH4, PH6, SE7, SE8, SE10, SE11, SE13, IO3, IO4, IO5
Maintenance		
8. Use of standard OGSS spare parts components	Use of standard OGSS spare parts components (batteries, inverters, controllers, etc.) which can accelerate the technical intervention from the Government and can create a local pool of know-how.	PH1, PH3, SE3, SE5, SE13, IO2
9. On-site learning process	Introduction of training courses on a) technical OGSS aspects, such as cleaning PV modules, checking batteries, collecting electricity fees, replacing fuses and fixing disconnected wires, b) links between electricity supply and other economic activities, c) monitoring, assessment and reporting OGSS outcomes (fault diagnostics etc). Local training should include any present or future auxiliary equipment (such as batteries, etc.) in case the OGSS needs expansion/adjustment to new environment. Learning should be problem-based.	PH1, PH2, PH3, SE3, SE4, SE5, SE6, SE8, SE9, SE11, SE13, SE14, IO2, IO6
Monitoring		
10. Demonstration of the OGSS projects	Demonstration of the OGSS operation & maintenance, for example, to the youth of the village.	PH3, SE5, SE6, SE7
11. Exchange of lessons learnt between villages	Exchange of lessons learnt through discussions, exchange of visits to OGSS etc. Need emphasised from (New Zealand Government, 2016) and (Niez, 2010).	PH3, SE3, SE4, SE5, SE6, SE9
12. Constant OGSS environmental assessment	Looking for possible impacts from the use of OGSS or/and batteries (as battery leaks might be a very serious environmental problem once occurred).	PH2, PH6, SE3, IO6
13. Financial assessment of the OGSS & constant update	For example (if systems would come with batteries), financial assessment of battery sizing which is considered as “key” to achieving the most economical arrangement out of OGSS (Agence Francaise et Developpement, 2014). ^a	PH3, PH6, SE3, SE4, SE10, SE14, IO6, IO7
14. Optimization of the metering system	Request from the Government of a study on the best rural metering strategies at a global level (Niez, 2010). Villages should make sure that payments are all made as this demonstrates a fully reliable electricity system which is promising in terms of future profits (as might attract investors for further expansions).	PH1, PH5, SE1, SE11, IO2, IO6

^a If too many batteries are installed, the investment has no or limited savings over the period compared to the diesel solution. If, on the other hand, there are too few batteries, this would cause the diesel component to start too frequently, reducing the achieved efficiency and savings.

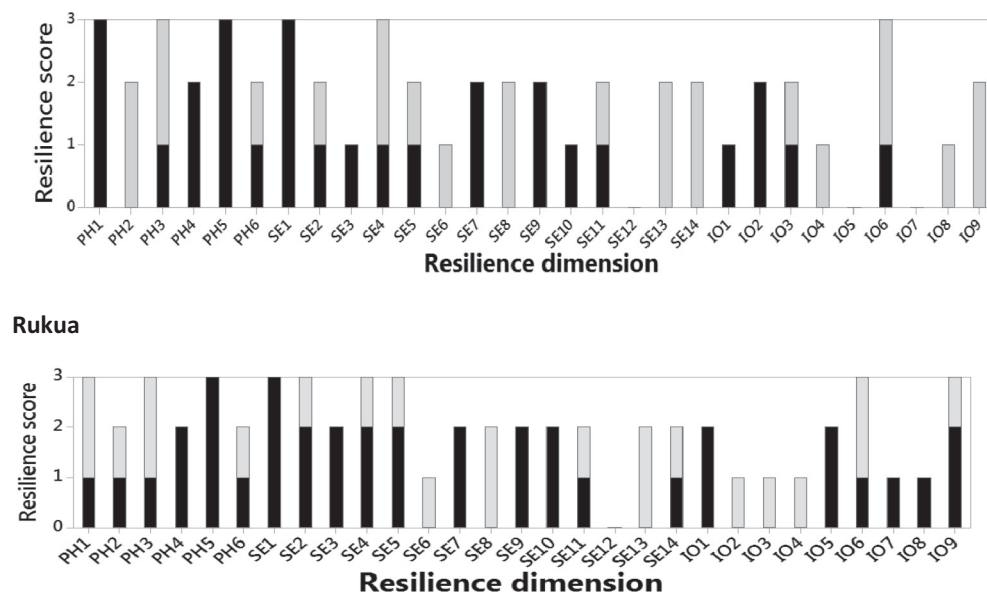


Fig. 1. The baseline village resilience dimensions (black) with the additional resilience benefits (grey) from the proposed intervention.

experimentation. The focus of the intervention was to strengthen the linkage between the installed RE technology and society. The proposed interventions covered the areas of energy maintenance, management and monitoring (termed the MMM intervention hereafter). We have identified a set of tasks which could further furnish the villages with improved resilience, as explained through the resilience framework (Table 3).

Based on the developed understanding of the village systems, we have theoretically applied the MMM-interventions to the existing situation in both villages and then we have assessed the projected effect on the resilience portfolio (Fig. 1). For both Naceva and Rukua, an increase in resilience was indicated in many PH, SE and IO resilience dimensions because of the MMM intervention.

The indicative increases in resilience through the additional MMM interventions suggest that the way the solar systems were initially implemented missed opportunities for building resilience. The additional MMM intervention helped strengthen the interface between society and technology. This is particularly the case for SE8 (paradigm shift), SE13 (improvisation) and SE14 (ownership) which were low in the surveyed situation but which would likely be strengthened using the MMM intervention. This indicative analysis demonstrates the potential for building further resilience through interventions which would shift the focus on the interaction between technology and society.

4. Discussion

4.1. Technologies and community resilience

Vulnerability has been described as “a bridge that connects the physical impacts of climate to adaptations in social-ecological systems” (Malone and Engle, 2011). The impacts of extreme conditions on quality of life, energy consumption and health of communities have been studied by the scientific community, e.g. (Santamouris and Kolokotsa, 2015) and building resilience concerns creating positive outcomes despite high-risk status (Eells, 2016). Immense efforts are undertaken on modelling future climate projects, such as the global IPCC and Pacific region (Australian Aid, 2011) and then promoting strategic and operational responses within government and private sector. However, sometimes, regional and national umbrellas prove limited in their scope of dealing with local renewable energy issues (Michalena and Hills, 2012); and downscaling of these futures to a spatial scale relevant to local-level vulnerability and construction of place-based resilience remains challenging. Thus, creating communities

that are able to make decisions will strengthen their adaptive capacity and flexibility and comprehensively respond to the uncertainty of climate change remains a priority at a local scale.

Community resilience has been touted as a key strategy for managing increased disaster risk under climate change (e.g. Tompkins and Adger, 2004; Nelson, 2011; Wise et al., 2014). One determinant of resilience is choices made at the household level, for example through personal lifestyle choices, behaviour and willingness to support climate change policy initiatives (Elrick-Barr et al., 2016b) or by simply “using challenges for growth to make future hardships more manageable” (Eells, 2016). The household as a boundary of activity is relevant to indoors activity and the role of appliances and behaviour to energy consumption (Pothitou et al., 2016; Pothitou et al., 2017). To increase resilience, communities need to increase adaptive capacity, although the specific degree to which the household is a venue for adaptive action remains largely unclear (Wamsler and Brink, 2014; Hughes and Sarzynski, 2015). In this process of increasing adaptive capacity the need for enhancement of social capital has been suggested by authors (Gawith et al., 2016). Enhanced social capital turns “disaster stricken communities into active participants, rather than vulnerable communities at a state of helplessness” (Berke et al., 2008).

In the case of PSIDS, community resilience tends to be strongly correlated with economic resources (Manyena, 2006). This linkage between economic development and resilience would seem to be a strong driver behind rural electrification as spelled out by the Fijian Prime Minister at Rukua. However, the socio-economic characteristics of rural Pacific communities seem to leave little room for cost effectiveness when it comes to electrification. In Fiji, large subsidies of up to 95% of the cost from the government to cover renewable energy installation and minimal and problematic fee collection (Republic of Fiji, 2014) means that substantial community benefits are required to justify such investment. This situation emphasises the need for innovations to be holistically planned and implemented to optimise development benefits; the cases presented in this paper demonstrate weaknesses in contextualising the innovation and thus erosion of resilience benefits.

Authors have identified concerns with technological innovations that are promoted to deal with contemporary challenges but presented as top-down and “prepackaged” approaches with little empathy for the societal context (e.g. (Smith et al., 2014)). Furthermore, other authors note that the “whole notion of technology being transferred and embedded as a package into a conforming recipient context begins to look problematic” and thus the need to develop analyses which contribute to understanding of the socio-technical context (Geels, 2004; Geels and

Kemp, 2007; Bryne et al., 2011). Numerous approaches have been developed in the past years towards helping communities exploiting best the energy systems (Kokologos et al., 2014; Laskari et al., 2016). For the Pacific, in which the largest sector for inward climate change development assistance is renewable energy (Atteridge and Canales, 2017), and which has over USD 1 billion of pledges predominantly for renewable energy (New Zealand Government, 2016), the analysis presented in this work points to a necessity for further research to enhance contextualisation of energy innovations to accrue resilience gains.

4.2. Building resilience through renewable energy innovation

International and national interests in climate change in the Pacific are high with significant inward investment in both mitigation and adaptation. The “Mega-What” question whether “renewable energy is finally for people or for Feed-In-Tariffs, trade and targets” (Hills and Michalena, 2013) has preoccupied researchers. With a lens on rural communities, the work presented here aimed to promote an innovative approach in the implementation of off-grid renewable energy schemes. Using a resilience framework made up of physical, socio-ecological and institutional dimensions, results from two Fijian sites demonstrated that the increased electricity supply through renewable energy does lead to some resilience gains but that there are considerable missed opportunities for further gains which had not been explored or exploited. If it is agreed that “renewable energy governance might block the technically feasible” (Michalena and Hills, 2013), the here analysis suggested that these further resilience gains could be captured through additional interventions which strengthen the socio-technological interface.

In both cases of Rukua and Naceva, there has been no evidence that the implemented innovations have succeeded to meet the resilience building needs of the village. In Rukua, for example, quick recovery and restoration of systems to normal operating state (Khodaei, 2014) was not achieved and a partial operating system was unrepaired for months. Although, it is argued that RE can be used to develop resilience (Perera et al., 2015), three key aspects enhance energy systems resiliency: *prevention, recovery and survivability* (Electric Power Research Institute, 2009) did not apply in the case of Rukua. The use of the electricity was mainly for activities which did not defer resilience and energy conservation was not prioritised as real costs were subsidised by the government by up to 95% (Republic of Fiji, 2014). In any case, the RE dimensions of resilience suggested in this study can be tested through further research.

Innovation is also related to location (Tim, 2002). This study reveals that, through a design of technological interventions which focus on socio-technological interface, place-based resilience can be increased through improved planning. As (Gupta et al., 2010) state, “we increase adaptive capacity when we enable social actors to design new institutions and inform existing ones to better respond and adapt to a changing environment”. (Meinzen-Dick and Knox, 2011; Fidelman et al., 2016) argue that it is important to create decentralised and more participatory and collaborative conditions in the management of energy resources. It is this element that permits the innovation to be fully contextualised and flourish.

Thus, for RE, or other innovations, to become a more impactful agent promoting, appropriate intervention planning should be in place. In this study we framed this planning around the MMM interventions (management, maintenance and monitoring). At a local level, increase of ownership, supported economic development and improved equitability are the main elements that should prevail. Enhancing the local ownership of the innovation systems is especially important, as for the time being there is the feeling that the solar systems belong to the government and are under the responsibility of the government.

5. Conclusions

The case studies are focussed on the process of innovation adoption

and performance in indigenous and vulnerable island communities which encapsulate many of the contemporary sustainable development challenges (Bryne et al., 2011; Connell, 2013; Kelman et al., 2015). The work was targeted at research gaps associated with energy innovation in a contemporary development context, in order to demonstrate how institutional and behavioural factors as well as national cultures shape the innovation diffusion which has implications for both investors and decision-makers (Masini and Menichetti, 2013; Desmarchelier and Fang, 2016).

Our work confirms and strengthens previous research findings according which although technology foresight has been increasingly undertaken by developing countries to identify technologies whose adoption might serve as a platform for future economic growth, those foresight activities have not necessarily resulted in well-developed policy initiatives (Bryne et al., 2011; Feigea and Vonortas, 2016). In the cases presented here, there was significant additional potential for innovative systems to build resilience through improving the social-technological surrounding nexus as well as to reduce unintended and negative social consequences of the innovation implementation. The challenge of turning innovative technology into a more holistic development instrument, is addressed in this work through improved MMM (management, maintenance and monitoring) interventions alongside RE systems installation. Analysis of the MMM intervention illustrated the potential for strengthening of the technical-social interface and further accrual of resilience benefits to the community.

Innovation is seen as a key element in transition research and socio-ecological resilience focussing on human well-being in the face of uncertainty and change (Olsson et al., 2014). However, this research identifies that in vulnerable and indigenous communities, the process concerning innovation adoption and diffusion needs to be planned beyond just technological deployment, and inculcate a holistic approach across the cultural, social, economic dimensions. Much of the global aspiration involved in transitioning toward the Sustainable Development Goal targets will involve technology-based innovation, but the work presented here provides a salutatory and disquieting backdrop for more indigenous and vulnerable communities which are most at risk to sustainable development challenges.

Access to development finance and the need for technological transfer to proceed to more sustainable and low-carbon futures reflect the present global rhetoric from Pacific islands and other Small Island Developing States (SIDS). However, even with mobilised resources and ready access to technical innovation, without more holistic planning of the innovation process there is a concern that many resilience outcomes will be weak and sub-optimal. The existential threats to many local communities, and some nations, in the Pacific, may mean that sub-optimal innovation will not be enough.

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Jeremy M. Hills is Director of the Institute of Marine Resources at The University of the South Pacific and Adjunct Professor at the Sustainability Research Centre, University of the Sunshine Coast (Australia). He is a Chartered Environmentalist who has worked in over 45 countries in Africa, Asia, Caribbean, Europe, Middle East, South America and the Pacific. He worked for many development partners including EU, UNDP, UNEP and UNESCO, national agencies and non-governmental bodies. He has contributed to over 60 development projects and undertaken a diversity of research on environment, development and climate change.

Evanthie Michalena is a senior renewable energy expert with a professional experience of 23 years in the energy sector. She has previously worked in the Public Power Corporation of Greece (PPC) and she now sits in the Secretariat of the Greek Energy Regulator. She has participated actively in energy transition activities of > 40 countries. Since 2005 she is a consultant to private companies, the European Commission, GGGI and the United Nations, since 2015 she is adjunct Associate Professor at the Sustainability Research Centre, University of the Sunshine Coast (Australia) and since 2017 she is adjunct Professor at the University of Fiji and Board Member of the Centre of Renewable Energy of the University of Fiji (CORE).

Konstantinos J. Chalvatzis is a Professor in Business and Climate Change at Norwich Business School and Tyndall Centre for Climate Change Research (UK). He has held visiting roles at the Department of Geographical Sciences at the University of Maryland, at the School of Economics Statistics and Management at the University of Bologna and at the Department of Mechanical Engineering at the University of Applied Sciences of Piraeus. His research focus is on technological transitions and futures in the energy sector and the role of innovation in systematic resilience. His research has attracted consortium funding in excess of €23 m.